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MAY 1961

A DOUBLE-CHARGE TECHNIQUE TO MEASURE FACE-ON BLAST

W. Olson
J. Wenig

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Department of the Army Project No. 503-04-002
Ordnance Management Structure Code No. 5010.11.815

BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

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W. Olson

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Terminal Ballistics Laboratory

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A B E R D E E N   P R O V I N G   G R O U N D ,   M A R Y L A N D

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MEMORANDUM REPORT NO. 1347

WCOlson/JWenig/bjk
Aberdeen Proving Ground, Md.
May 1961

A DOUBLE CHARGE TECHNIQUE TO MEASURE FACE-ON BLAST

ABSTRACT

This report presents measurements of air blast parameters at the midpoint of a line joining two equal weight explosive charges. The explosive used was 50/50 Pentolite with dual one or eight-pound spheres being detonated simultaneously. The pressure transducer employed was a BRL "pancake" pressure gage employing a synthetic piezoelectric ceramic as the sensing element. Pressure, impulse and duration measurements were obtained for scaled distances of 1.5 to 3.2 ft/lb$^{1/3}$ for comparison with data derived by other techniques.

INTRODUCTION

In studying the response of targets[1,2*] to the transient loads of air blast, two parameters of interest are the peak overpressure and positive impulse associated with the blast wave. Peak pressure and impulse usually are designated as either "side-on" or "face-on." Side-on (or hydrostatic) pressure and impulse can be measured by a transducer whose sensing element is parallel to the direction of propagation of the wave. Face on (or dynamic) pressure and impulse are usually measured by a sensing element which forms part of a large rigid surface situated normal to the incident blast wave.

Face-on blast experiments at the BRL consist primarily of measurements of pressure-time histories with piezoelectric gages flush-mounted in a large reflecting surface and subjected to air blast at normal incidence, or of measurements of impulse only with a mechanical gage consisting simply of a moveable plug mounted in the surface[3].

Each of the above experimental methods can have limitations. In the case of flush-mounted gages, it is difficult to calibrate the gage directly. Calibrations are obtained indirectly by measurements of incident shock velocities. From these incident velocities, the incident pressure is determined from the Rankine-Hugoniot relationships. Then a theoretically determined ratio of incident to reflected shock pressures is applied[4]. Furthermore, at small distances from the explosive, shock loadings by the blast may exceed the mechanical performance capabilities of the gage and hence result in a distortion of the response. The mechanical or plug method can only be used to measure face-on impulse. The quantity which it measures may be positive impulse, total impulse, (i.e., positive less negative), or some intermediate value depending on the mass of the plug and the duration of the blast wave.

It has long been realized that the face-on reflection of a blast wave from a rigid surface can be simulated by the simultaneous detonation of two identical explosive charges. The plane lying midway between the charges can represent a rigid surface. In fact, a model often used to describe the

* Superscript numbers denote references listed at the end of the report.

reflection process is depicted in Figure 1, where a "virtual charge" replaces the reflecting surface[5]. It is the purpose of this report to discuss some results obtained with a piezoelectric gage placed at the geometric center of two identical explosive charges which were detonated simultaneously, and to compare these data with data from the other methods.

PHYSICAL TEST SETUP

A pre-calibrated side-on piezoelectric gage was placed at the midpoint of a line joining the centers of two equal weight explosive charges (Fig. 2). Pairs of one or eight-pound spherical charges of cast 50/50 Pentolite were used for the experiments. The charge pairs were simultaneously initiated by an electronic circuit which applied a 5000-volt pulse to the "Engineers Special" electric detonators centrally located in the explosive spheres (see Fig. 3).

INSTRUMENTATION

Simultaneity of detonation of the pairs of explosive charges was achieved by means of an electronic circuit described in detail in Appendix I. A separate identical power supply, of low impedence, was used for each charge. Both supplies were triggered simultaneously by a common input. The peak voltage output of each supply is approximately five kilovolts. The energy source is a four micro-farad capacitor switched by means of a hydrogen thyratron. The pair of pulsed supplies made simultaneous firing more certain by reducing the possibility of high voltage flash-over across the lead wires which might have occurred if series or parallel circuitry were employed.

High speed photographs were taken to check the simultaneity of initiation of two charges. A commercial electronic shutter based on the Faraday principle was used. The effective exposure time of the camera was somewhat less than one microsecond. Figures 4, 5, and 6 show the luminous expanding shock front from dual one-pound charges at approximately 10, 50, and 75 μsec after initiation and indicate that simultaneity was achieved. A further check on simultaneity is obtained by observing the

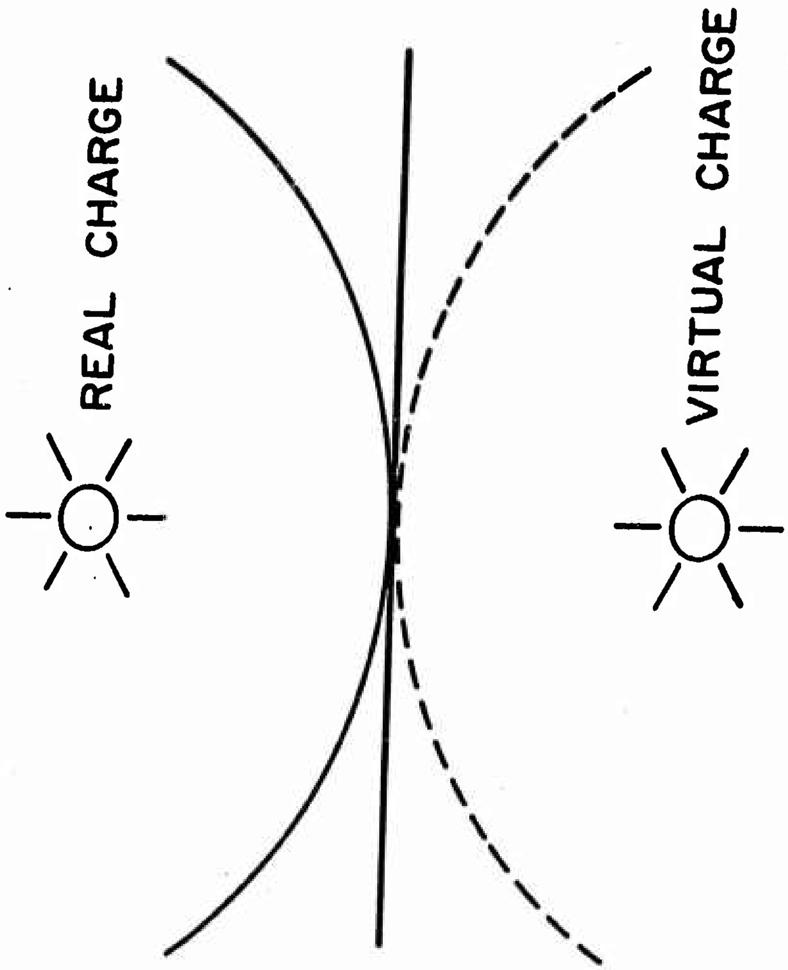


Figure 1

Figure 2

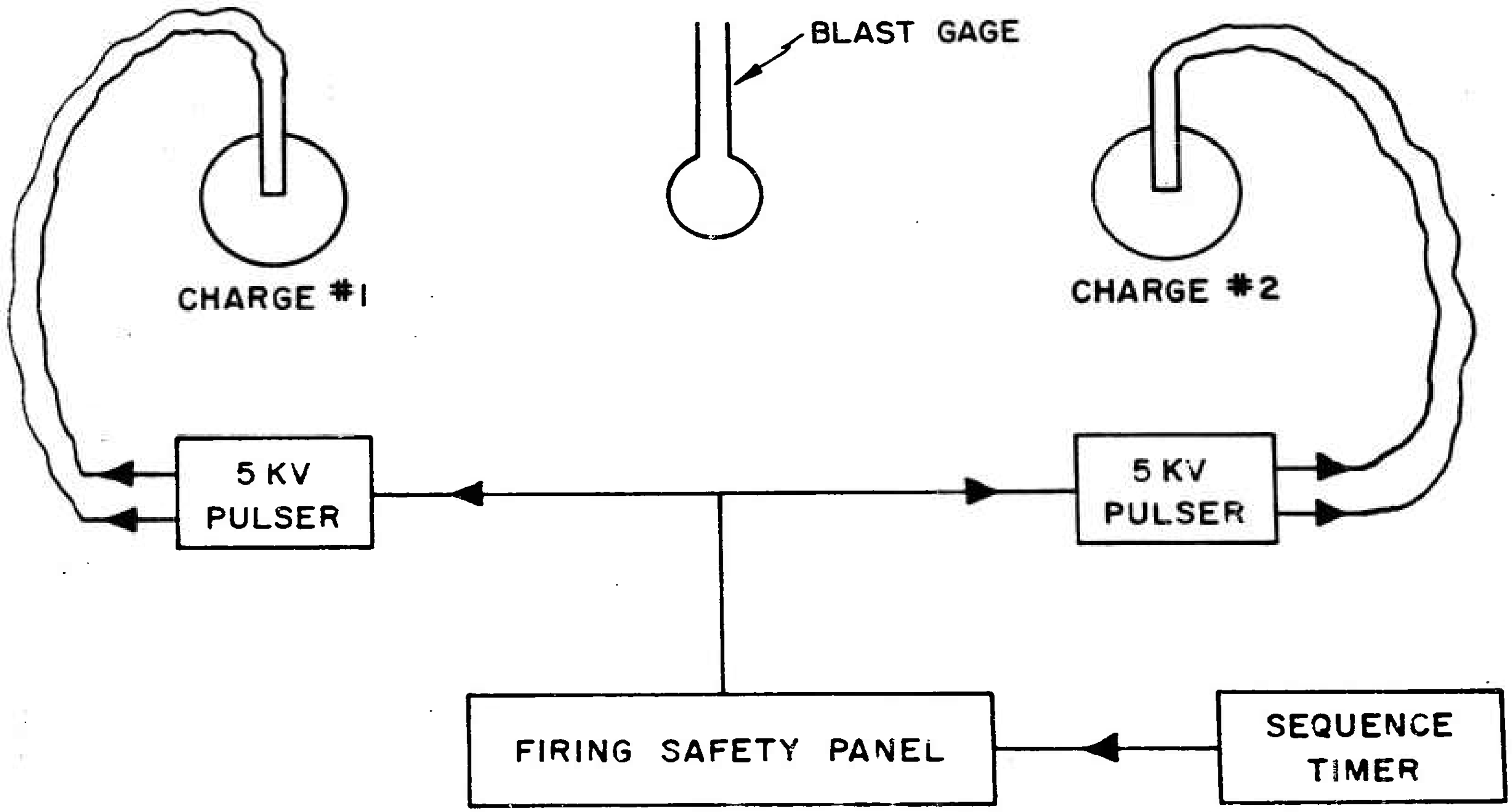

BLAST GAGE
CHARGE #1
CHARGE #2
5 KV PULSER
5 KV PULSER
FIRING SAFETY PANEL
SEQUENCE TIMER

Figure 3

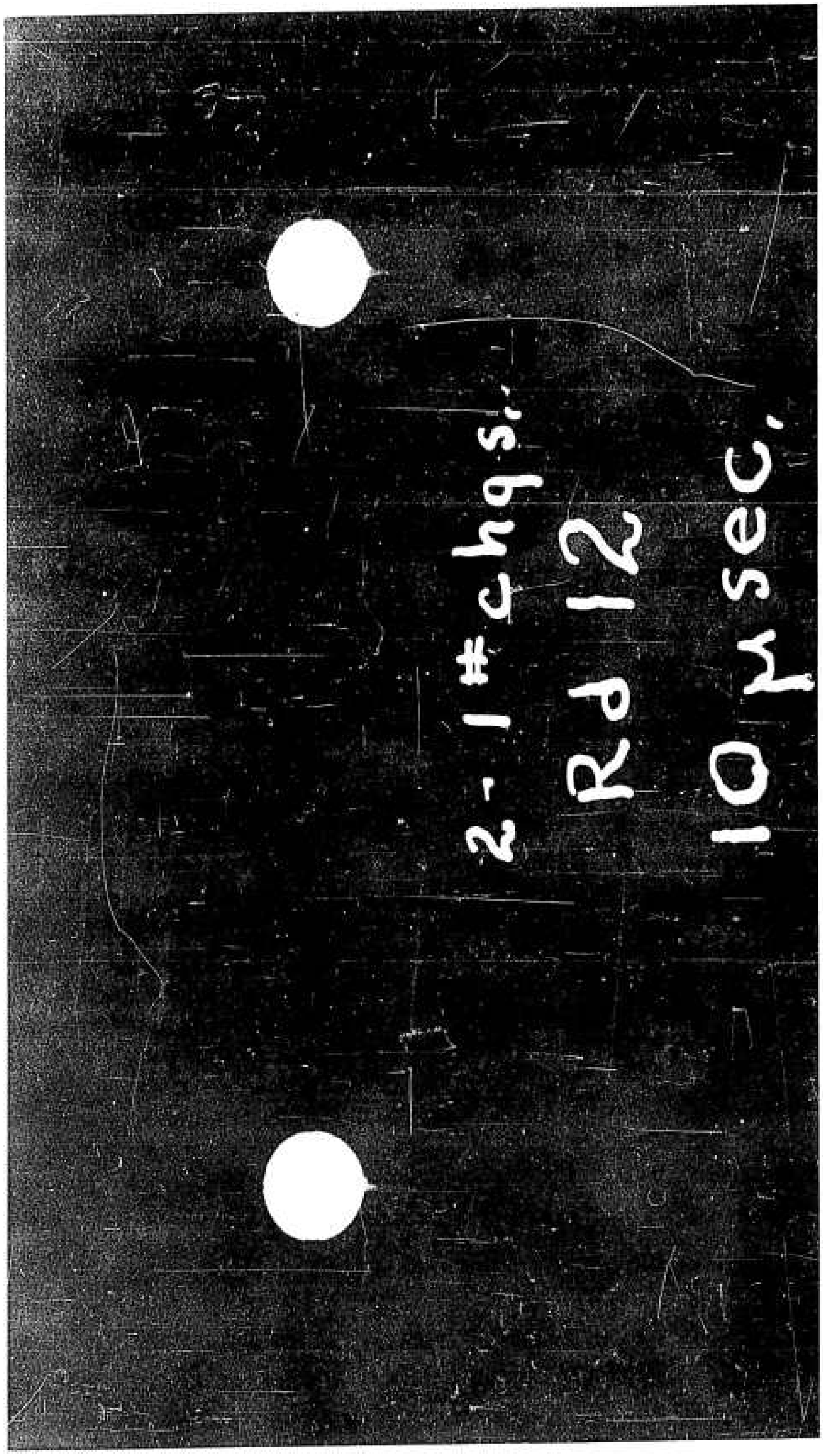
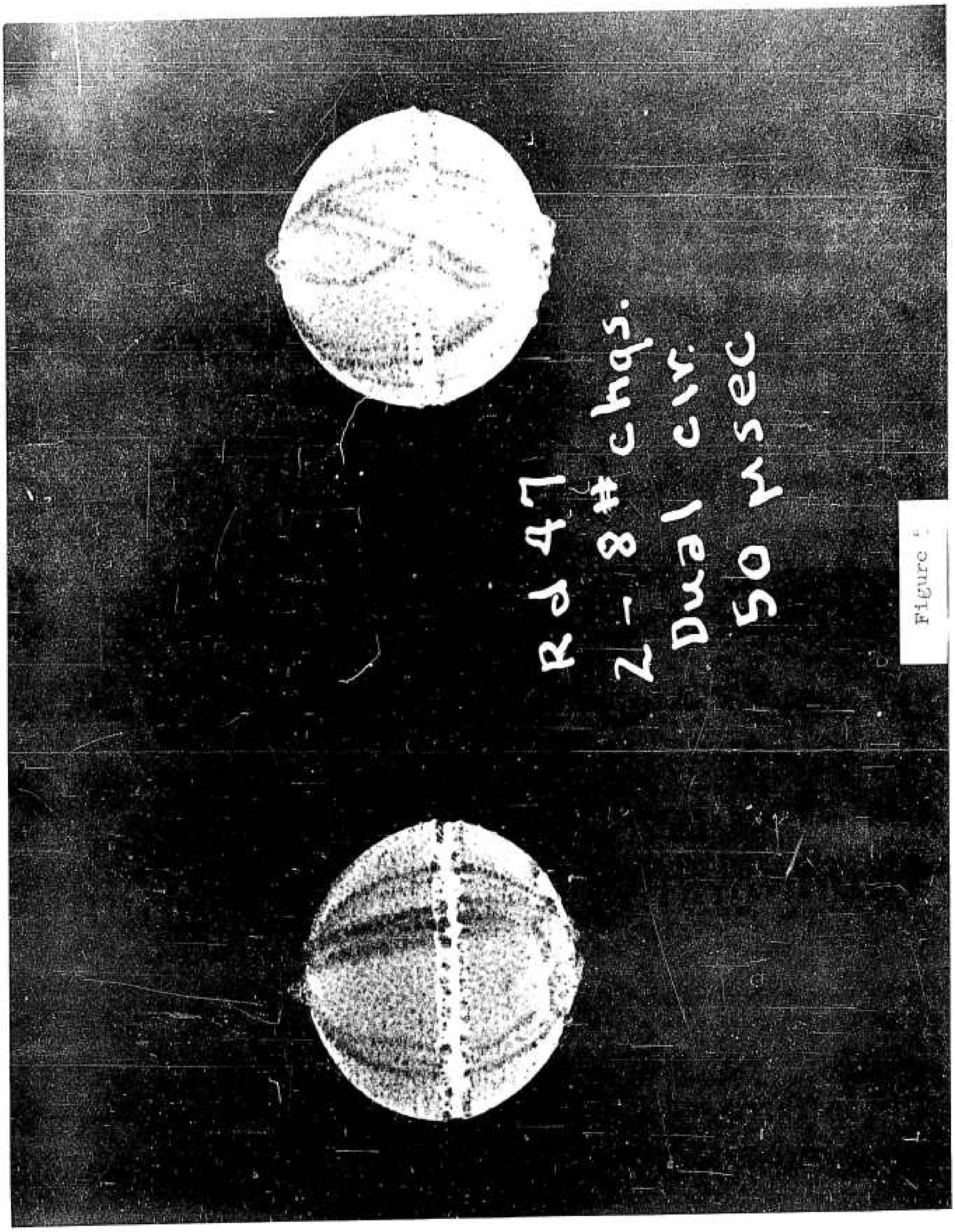


FIGURE 4



Figure

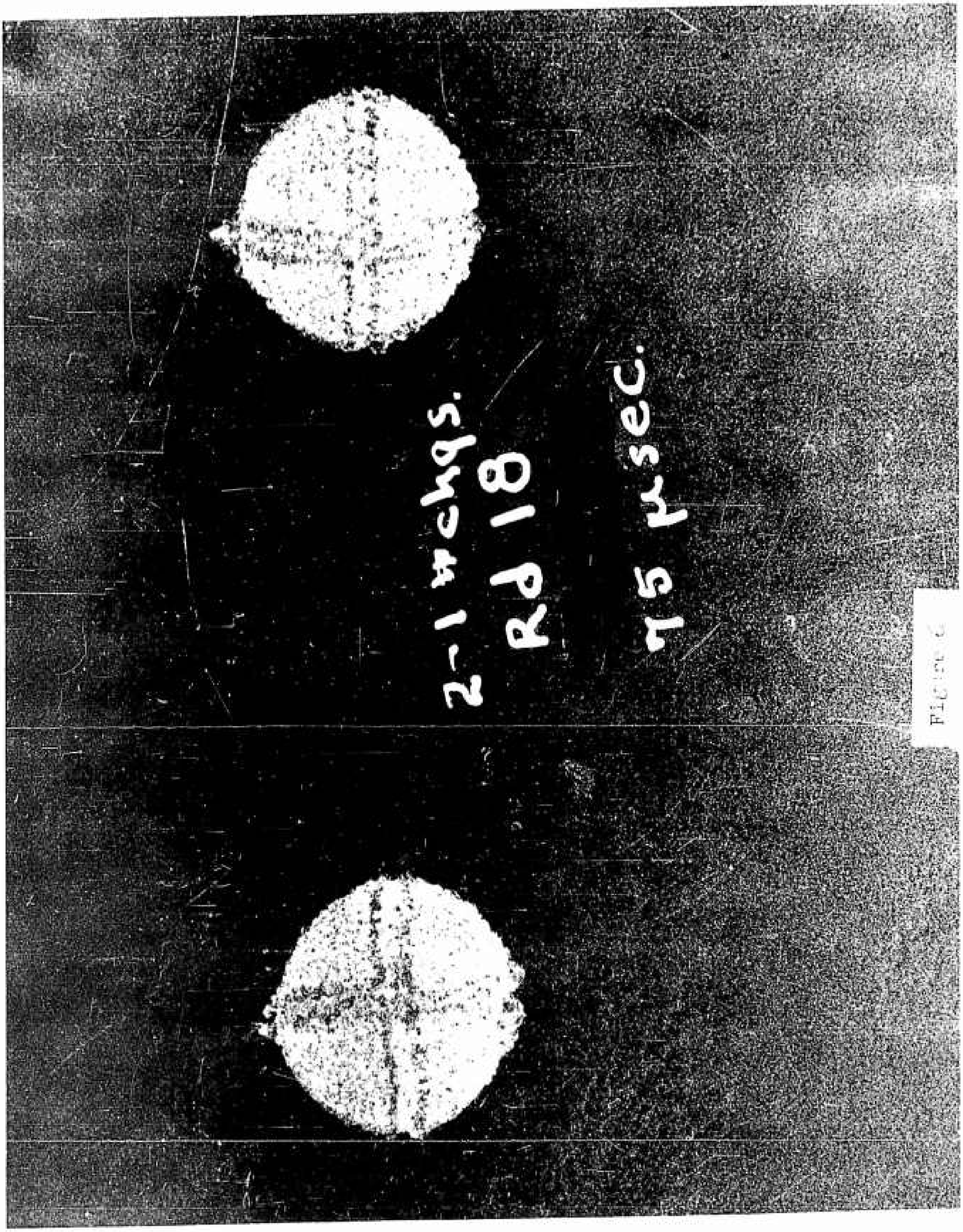


Figure 6

arrival of two shock envelopes at the gage as evidenced in Figures 7 and 8. Figure 9 is a schematic of the system used to photograph the shocks passing over the gage. An exploding wire[6] served as the light source and a lens was used to concentrate the light.

EXPERIMENTAL PROCEDURE

Prior to using the gage for these experiments, it was pre-calibrated in the following manner. The test gage was bracketed by another pair of piezoelectric gages which were used to sense time of arrival of an air blast wave and from which could be determined an average velocity of the wave over the interval. This average velocity is equivalent to the instantaneous velocity at the midpoint of the interval. Peak pressure of the wave could then be inferred from the Rankine-Hugoniot equation which relates peak pressure with velocity. By comparing the oscillographic output waveform of the test gage to a series of known calibration steps, a gage constant for the gage can be obtained. The "gage-constant" or sensitivity of the gage used in this series of experiments was 24.4 μμ coulombs per pound per square inch of impressed pressure.

Before firing, all Pentolite explosive charges were weighed, and although found to be very nearly equal to their nominal weights, were sorted in equal weight pairs. Each pair of charges was then suspended from an overhead cable (see Fig. 2) and guyed in position so that the pre-calibrated gage was positioned at the midpoint of the line joining the charge centers. The charges and gage were aligned by eye, and the distances from gage center to charge center measured by steel tape to an accuracy of $\pm$ 0.01 ft. The electrical detonators were positioned perpendicular to the ground plane and electrical leads were oriented to minimize the possibility of metal fragments from the detonators and lead wires from striking the gage. The signal generated by the gage was displayed and recorded via an amplifier and cathode-ray tube system and recorded by a General Radio streak camera (modified to produce film speeds of the order of two inches per millisecond).

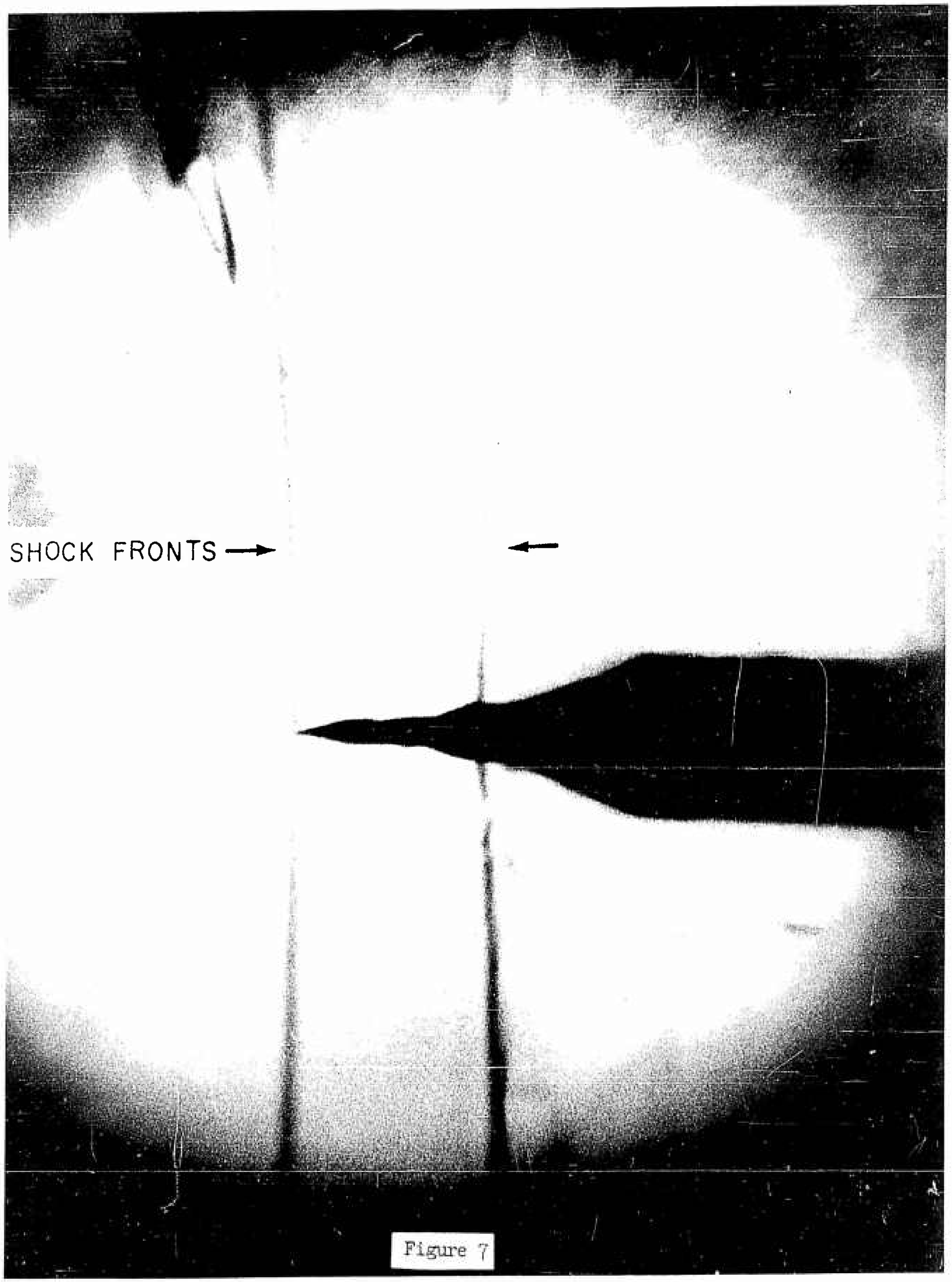


Figure 7

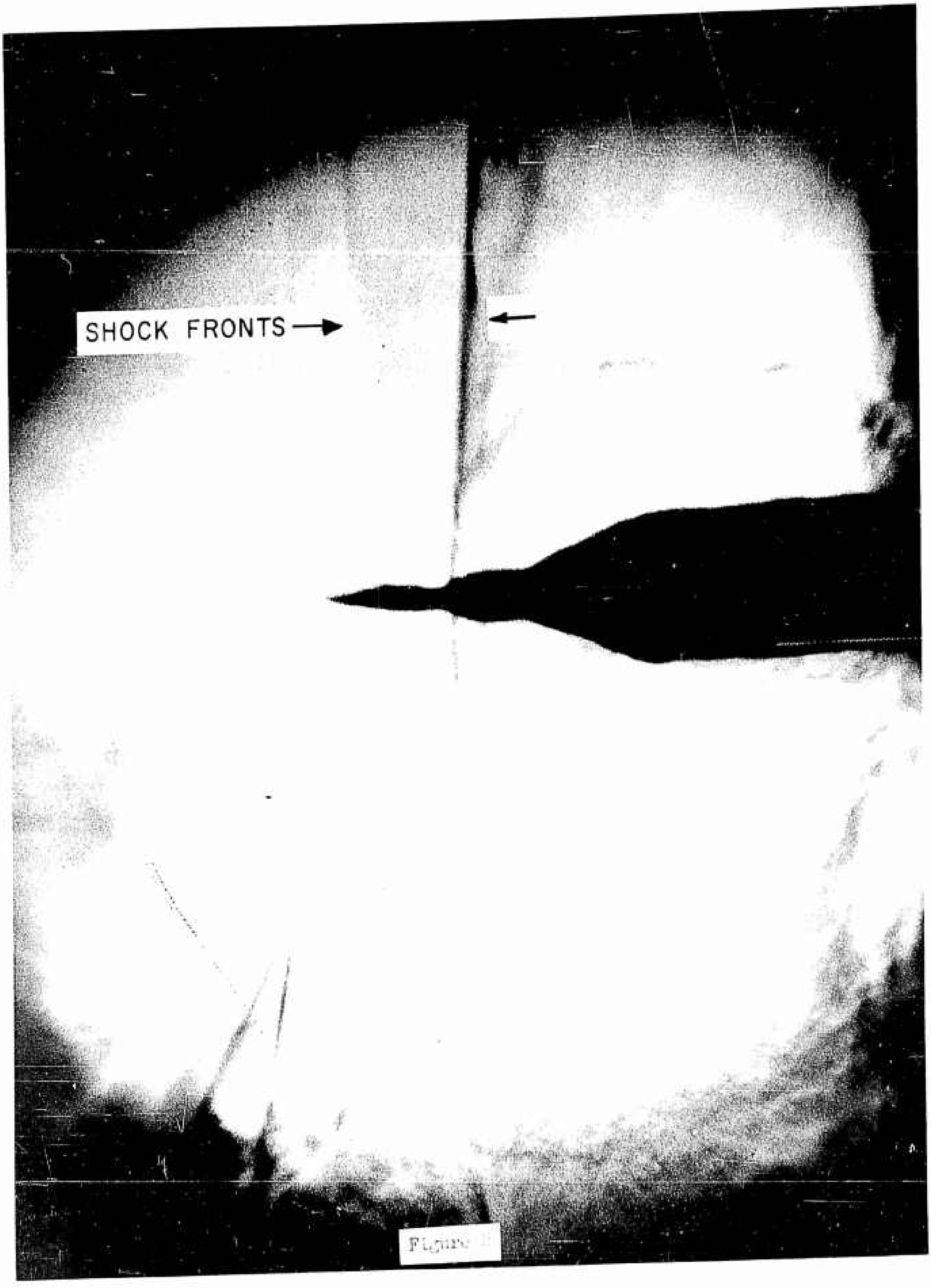


Figure [illegible]

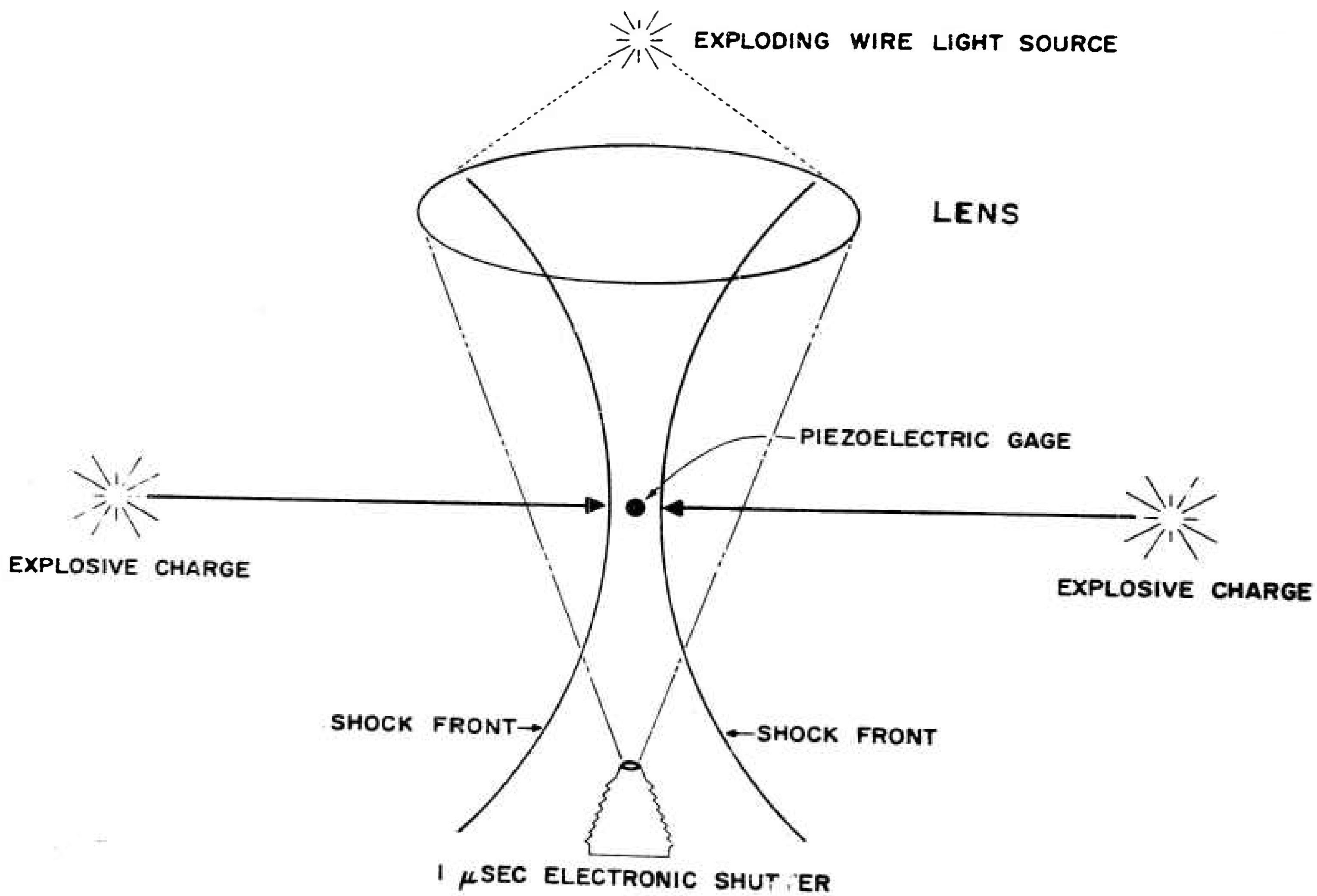

EXPLODING WIRE LIGHT SOURCE
LENS
PIEZOELECTRIC GAGE
EXPLOSIVE CHARGE
EXPLOSIVE CHARGE
SHOCK FRONT
SHOCK FRONT
1 μSEC ELECTRONIC SHUTTER

Figure 9

By this procedure, we obtained acceptable oscillograms at several scaled distances in to 1.5 $ft/lb^{1/3}$ from both charge weights used in these experiments. Figure 10 shows such an oscillogram recorded by detonation of a pair of one-pound charges at a scaled distance of 1.5 $ft/lb^{1/3}$. It indicates that acceptable pressure-time histories can be obtained at the limit of Hoffman & Mills[7] data.

COMPUTATIONAL PROCEDURE

Fifteen pressure-time histories were obtained from one-pound charges at scaled distances of 3.32, 3.0, 2.3 and 1.5 $ft/lb^{1/3}$. In addition, two check rounds were fired using eight-pound charges at a scaled distance of 1.5 Peak overpressure, positive impulse, and positive duration were measured from these oscillograms.

With individual gage KA's (gage sensitivities) established, peak overpressure was calculated from

$$P = \frac{H}{S} \times \frac{Q}{KA}$$

where

P = peak overpressure, psi.

H = height of initial peak of pressure-time history on the film record.

S = voltage calibration step size on the record.

Q = calibration charge, $\mu\mu$ coulombs.

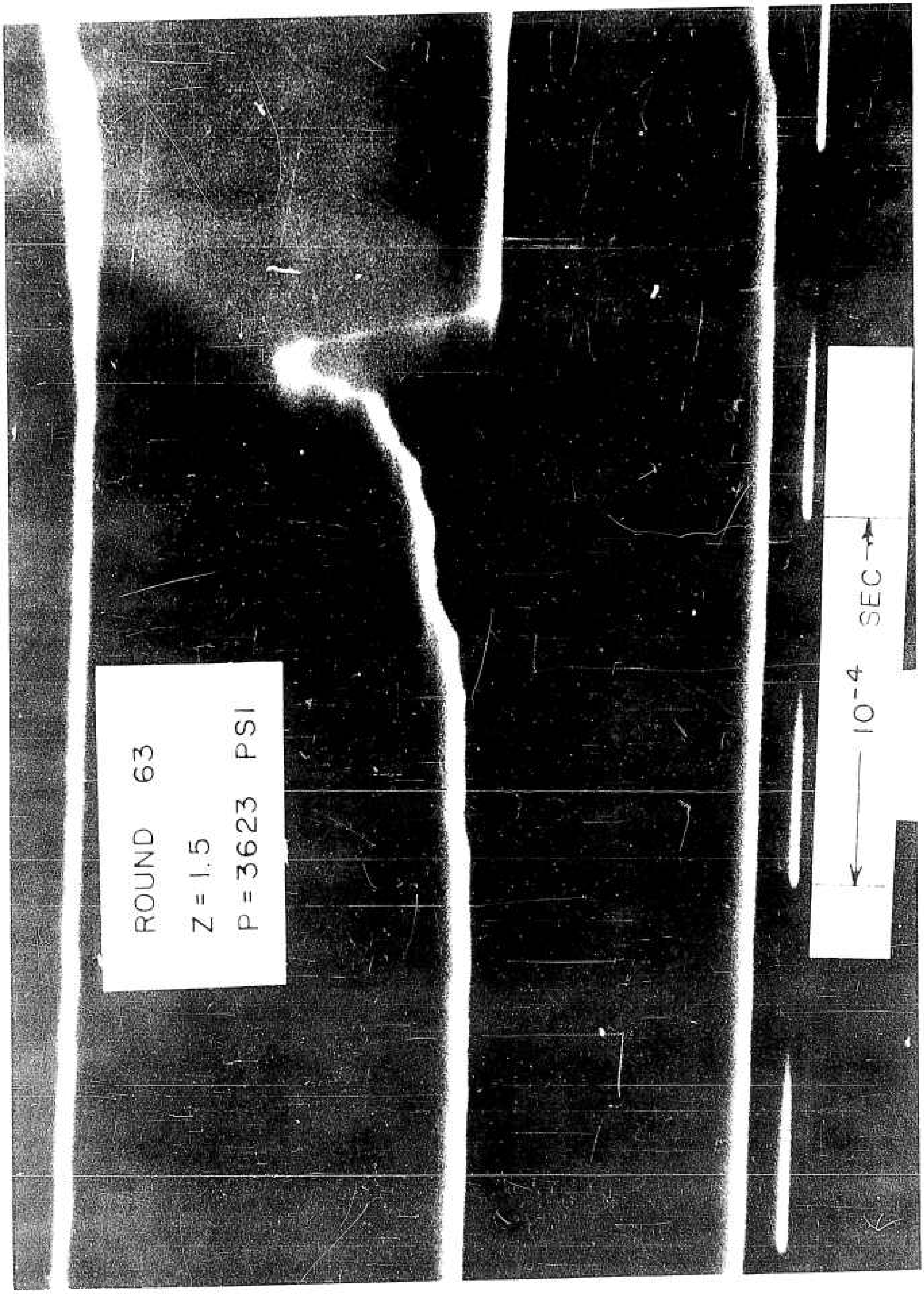
Heights H and S were measured by an arbitrary scale of the individual film records.

Positive impulse is defined as

$$I = \int_0^T p(t)dt$$

where p(t) is the overpressure as a function of time t and T is the duration of the positive phase. Integrating numerically we obtain

$$I = \frac{M \times Q}{KA \times US}$$


ROUND 63
Z = 1.5
P = 3623 PSI
10^{-4} SEC

where I = positive reflected impulse, psi ms.

M = area under the positive phase of the pressure-time history.

U = time scale factor, scale units/ms.

The area under the positive phase of the pressure-time history was computed by the trapezoidal rule from ordinate measurements on film records at small equal intervals.

Positive duration is obtained directly from the pressure-time histories and is defined as the time from the onset of the blast wave until the peak overpressure first returns to zero and before the pressure enters its negative phase.

RESULTS AND DISCUSSION

Table I presents a résumé of the data. Figure 11 indicates that the data of Table I are consistent with reflected pressure data from BRL Report No. 988[7] and reflected pressures inferred from the velocity data of BRL 984*[8]. The reflected impulse data are compared with data from BRL 988 and BRLM 1088 in Figure 12. It is apparent from these figures that the precision of our experiments is at least as good as the precision of the other methods. Our data were also consistent with and included in a compilation of experimental results from various sources in BRL 1092[9].

Figure 13 displays a record at $Z = 3.32\ \mathrm{ft/lb}^{1/3}$ from two blast waves which did not meet at the center of the gage. The initial portion of the pressure-time history shows the pressure imposed on the gage by a single charge. The pressure, 91.2 psi, agrees with incident pressures for this scaled distance inferred by other methods. A short time later the pressure is quickly modified to give a pressure which corresponds to the pressure at a short distance away from a reflecting surface. This pressure

* Reflected pressures were established from the incident pressures of BRL Report No. 984 by using the tables of pressure ratios, Preflected/Pincident, of the reflected shock wave versus the pressure ratio Pincident/Patmospheric of the incident shock wave for normal reflections in air in Reference 10.

TABLE I

REFLECTED PRESSURE, SCALED REFLECTED IMPULSE, SCALED DURATION vs. SCALED DISTANCE

ROUND NO.	NOMINAL CHARGE WEIGHT, LBS.	NOMINAL SCALED DISTANCE, "Z" $Z = R/W^{1/3}$	ACTUAL REFLECTED PRESSURE, PSI	ACTUAL SCALED REFLECTED IMPULSE $I/W^{1/3}$	ACTUAL REFLECTED DURATION $(\Delta t)(\text{MSEC.})/W^{1/3}$	SIDE-ON PRESSURE
48	8	1.5	3537	123.6	0.197	
56	8	1.5	3582	125.8	0.196	
63	1	1.5	3623	106.5	0.206	
26	1	2.3	1373	70.5	.301	
27	1	2.3	1579	90.9	.329	
28	1	2.3	1410	80.7	.332	
29	1	2.3	1461	80.7	.328	
70	1	3.00	599.6	55.8	.431	
12	1	3.32	418	47.4	.545	
13	1	3.32	423	42.9	.457	
14	1	3.32	390	38.4	.462	
18	1	3.32	367	41.6	.517	
19	1	3.32	368	38.0	.471	
20	1	3.32	390	43.4	.495	
* 9	1	3.32	405			91.2
** 7	1	3.32				92.1
** 8	1	3.32				93.7

* SHOCK WAVES DID NOT MEET DIRECTLY OVER THE GAGE, GIVING A "SIDE-ON" AND THEN A "FACE-ON" READING.
**ONE CHARGE OF THE MATCHED PAIR FAILED TO DETONATE, GIVING A "SIDE-ON" PRESSURE MEASUREMENT ONLY.

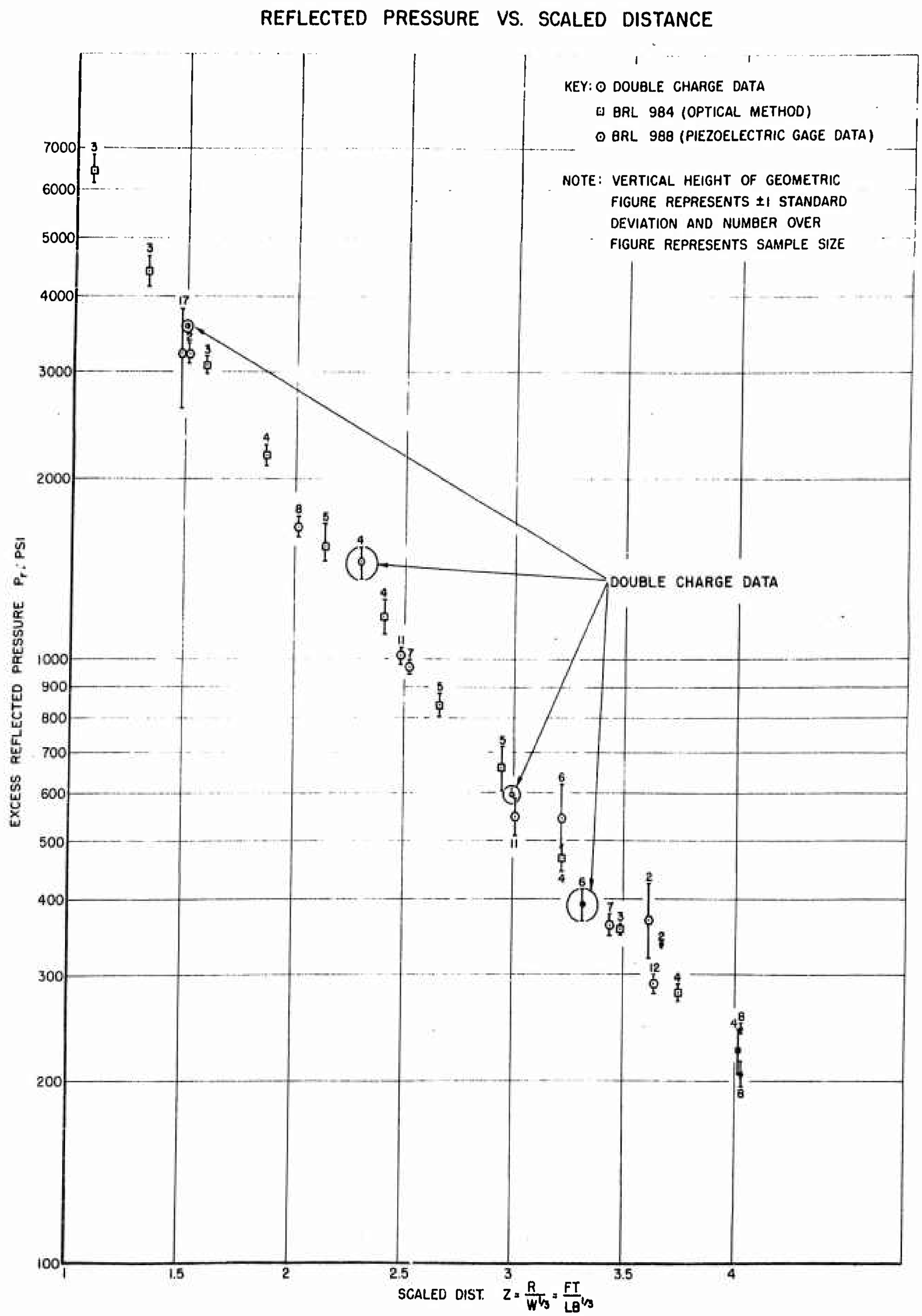

REFLECTED PRESSURE VS. SCALED DISTANCE
KEY: ⊙ DOUBLE CHARGE DATA
⊡ BRL 984 (OPTICAL METHOD)
⊙ BRL 988 (PIEZOELECTRIC GAGE DATA)
NOTE: VERTICAL HEIGHT OF GEOMETRIC FIGURE REPRESENTS ±1 STANDARD DEVIATION AND NUMBER OVER FIGURE REPRESENTS SAMPLE SIZE
DOUBLE CHARGE DATA
EXCESS REFLECTED PRESSURE P_r; PSI
SCALED DIST. $Z = \frac{R}{W^{1/3}} = \frac{FT}{LB^{1/3}}$

Figure 11

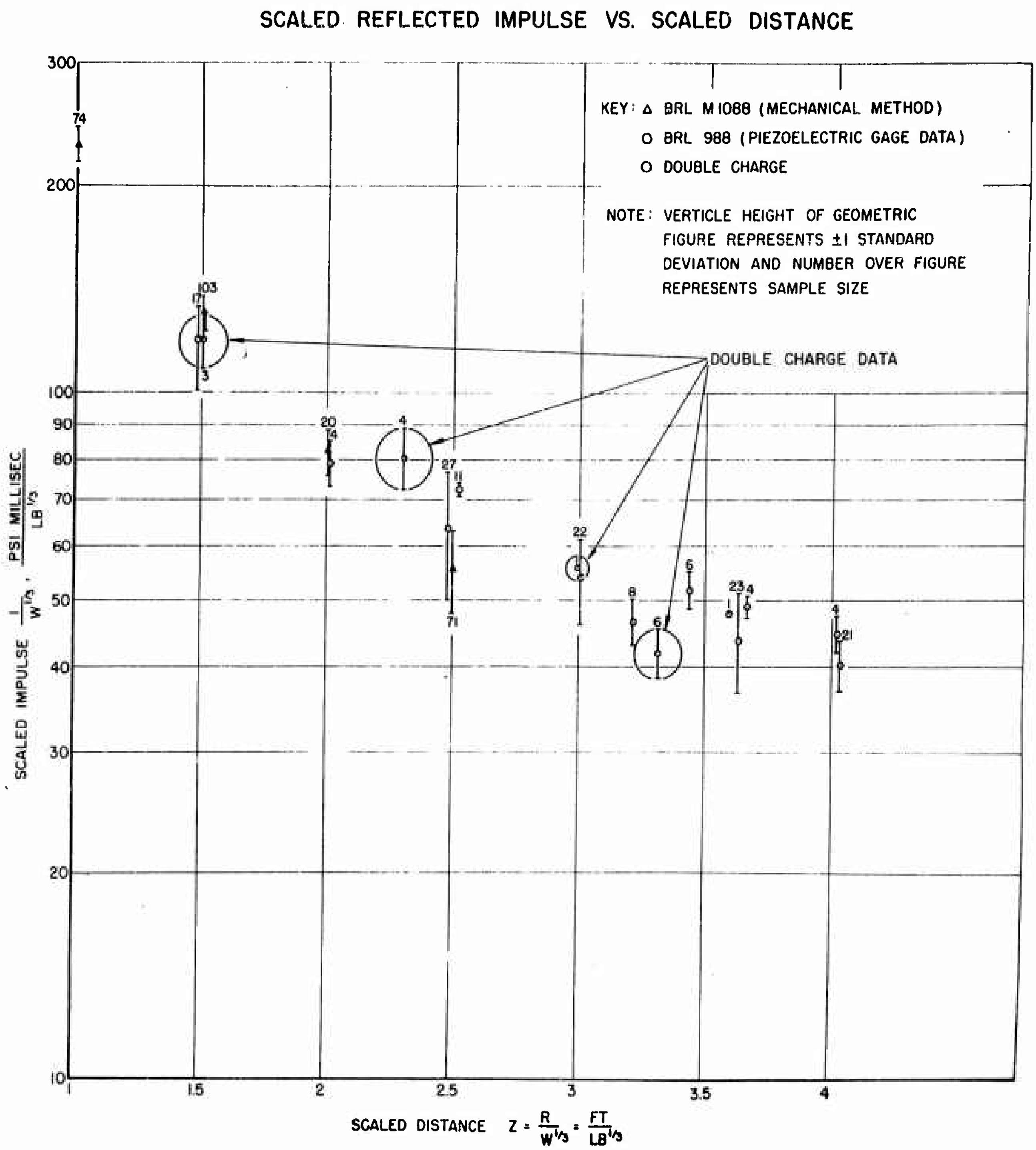

SCALED REFLECTED IMPULSE VS. SCALED DISTANCE
KEY: △ BRL M1088 (MECHANICAL METHOD)
O BRL 988 (PIEZOELECTRIC GAGE DATA)
O DOUBLE CHARGE
NOTE: VERTICLE HEIGHT OF GEOMETRIC FIGURE REPRESENTS ±1 STANDARD DEVIATION AND NUMBER OVER FIGURE REPRESENTS SAMPLE SIZE
DOUBLE CHARGE DATA
SCALED IMPULSE $\frac{I}{W^{1/3}}$, $\frac{\text{PSI MILLISEC}}{\text{LB}^{1/3}}$
SCALED DISTANCE $Z = \frac{R}{W^{1/3}} = \frac{\text{FT}}{\text{LB}^{1/3}}$

Figure 12

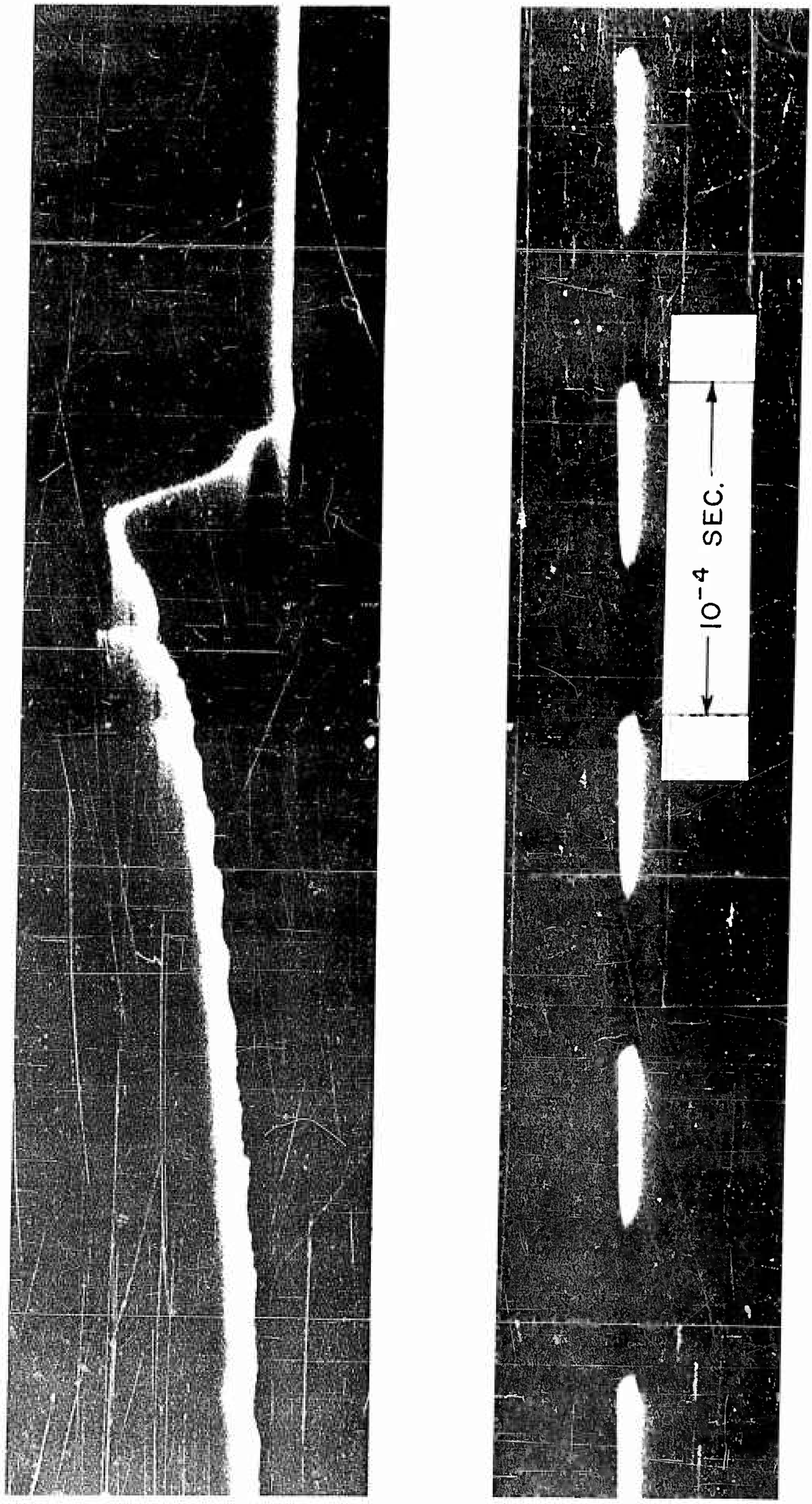


FIGURE 13

is approximately face-on pressure for this scaled distance. Rds 7 and 8 of Table I give predicted side-on pressure and impulse due to only one of the two matched pairs being detonated.

CONCLUSIONS

In this report, we have shown that we can obtain a satisfactory simulation of reflection of a blast wave from a rigid wall by simultaneous detonation of identical explosive charges. We have measured the pressure-time histories of the colliding waves using gages which were developed for side-on blast experiments, and have shown that these measurements agree with data obtained by other techniques. The data presented here constitute the first direct measurements with calibrated gages, of the pressure-time history of a face-on blast at scaled distances as small as $Z = 1.5\ ft/lb^{1/3}$.

W. Olson

W. OLSON

J. Wenig

J. WENIG

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9. Goodman, H. J. "Compiled Free-Air Blast Data on Bare Spherical Pentolite", BRL Report No. 1092, February 1960.

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11. Wenig, J. "A Pulse Amplifier for Use with Piezoelectric Velocity Gages", BRL TN No. 1138, July 1957.

APPENDIX A

Figure 3 is a block diagram of the field and recording setup. A safety firing panel applied a 135-volt positive pulse simultaneously to the grids of the type 5696 miniature thyratrons (see Fig. 14). The 400-volt output pulse of these tubes triggered the hydrogen thyratrons which supplied a 5 K.V. pulse to the explosive detonators and insured exact and simultaneous output to the explosive charges. The 5696 tubes were used in preference to the more conventional 2D21 tube since the former exhibit less delay and variation in firing time.[11] Although the 4C35 tube requires only a 100-volt trigger pulse to cause it to "strike", a 400-volt pulse was used. This combination of 135 volts applied to the 5696 tube biased at 15 volts, and 400 volts to the grid of the 4C35, insured exact and simultaneous output pulses to the explosive charges.

HIGH VOLTAGE PULSER 5 KV

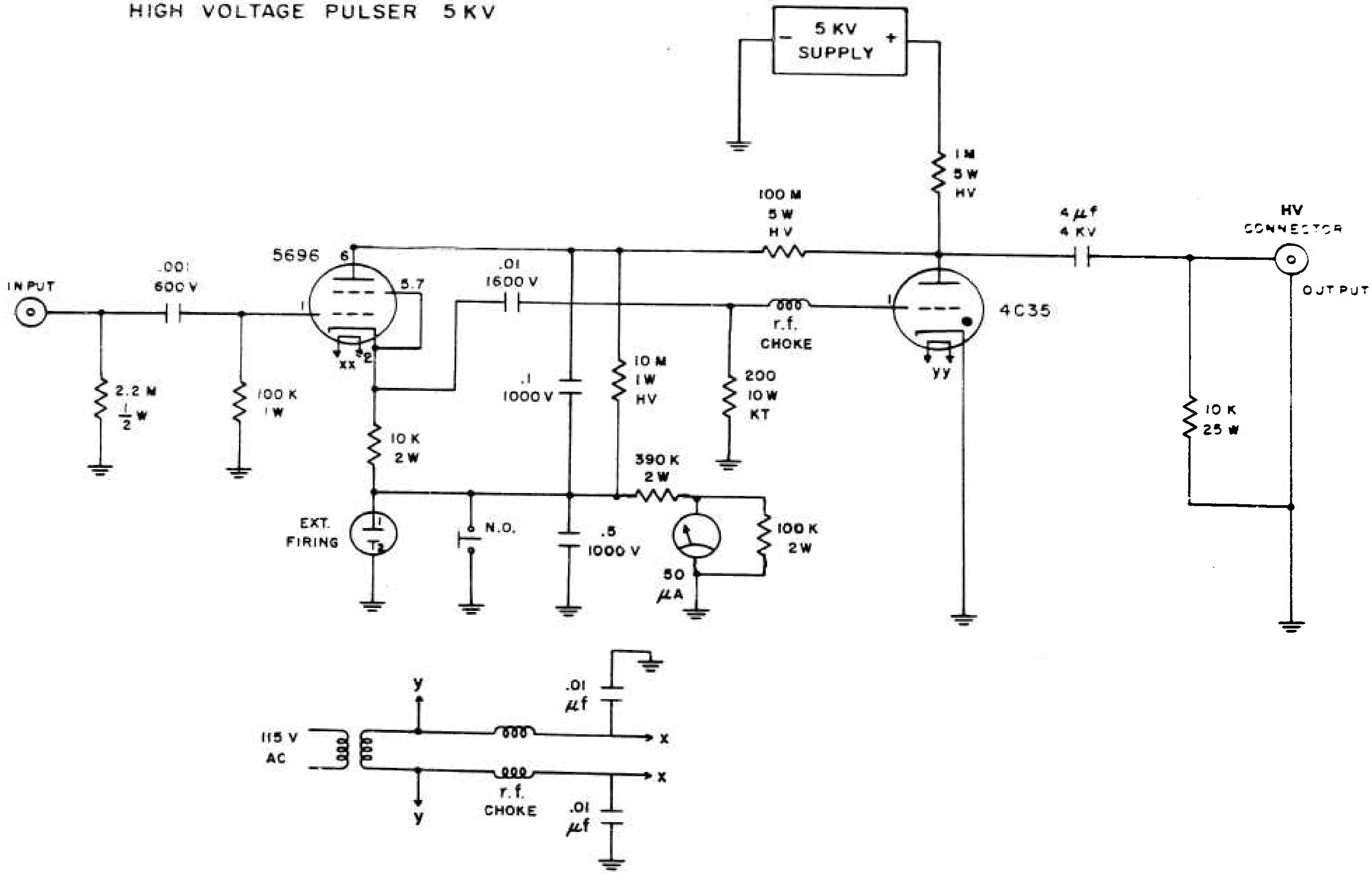

Figure 14

APPENDIX B

DESCRIPTION OF PIEZOELECTRIC GAGE

The blast gage used in these trials was of a type usually used to measure the side-on blast generated by small explosive charges. The gage head is in the form of a flat circular disc with beveled edges. It has an aspect ratio, or the ratio of width to thickness, of over ten to one so as to minimize perturbations of the shock it measured. The general construction of the gage is shown in Figures 15 through 17. The sensitive piezoelectric elements used were of lead metaniobate (obtained from the General Electric Corporation); Table II describes the physical properties of this material. For blast work, this material possesses some advantages. It has much higher sensitivity than quartz, or tourmaline. It has a very high Curie point (550°C), a very low acceleration response, and a low mechanical quality factor. A low mechanical quality factor, "Q", is desirable in a receiver transducer and helps to suppress spurious responses as well as providing more faithful reproduction of the impressed load. The sensing element consisted of a stack of two piezoelectric discs cemented together, with a silver tab between them. A small insulated wire was soldered to the silver tab and drawn through the gage housing and soldered to a coaxial connector at the stem end. Silicone vacuum grease was smeared around the stack and inside the gage housing so as to both weatherproof the gage and to provide good mechanical coupling between the lead metaniobate and the diaphragm. The diaphragm was then drawn tightly into place with screws.

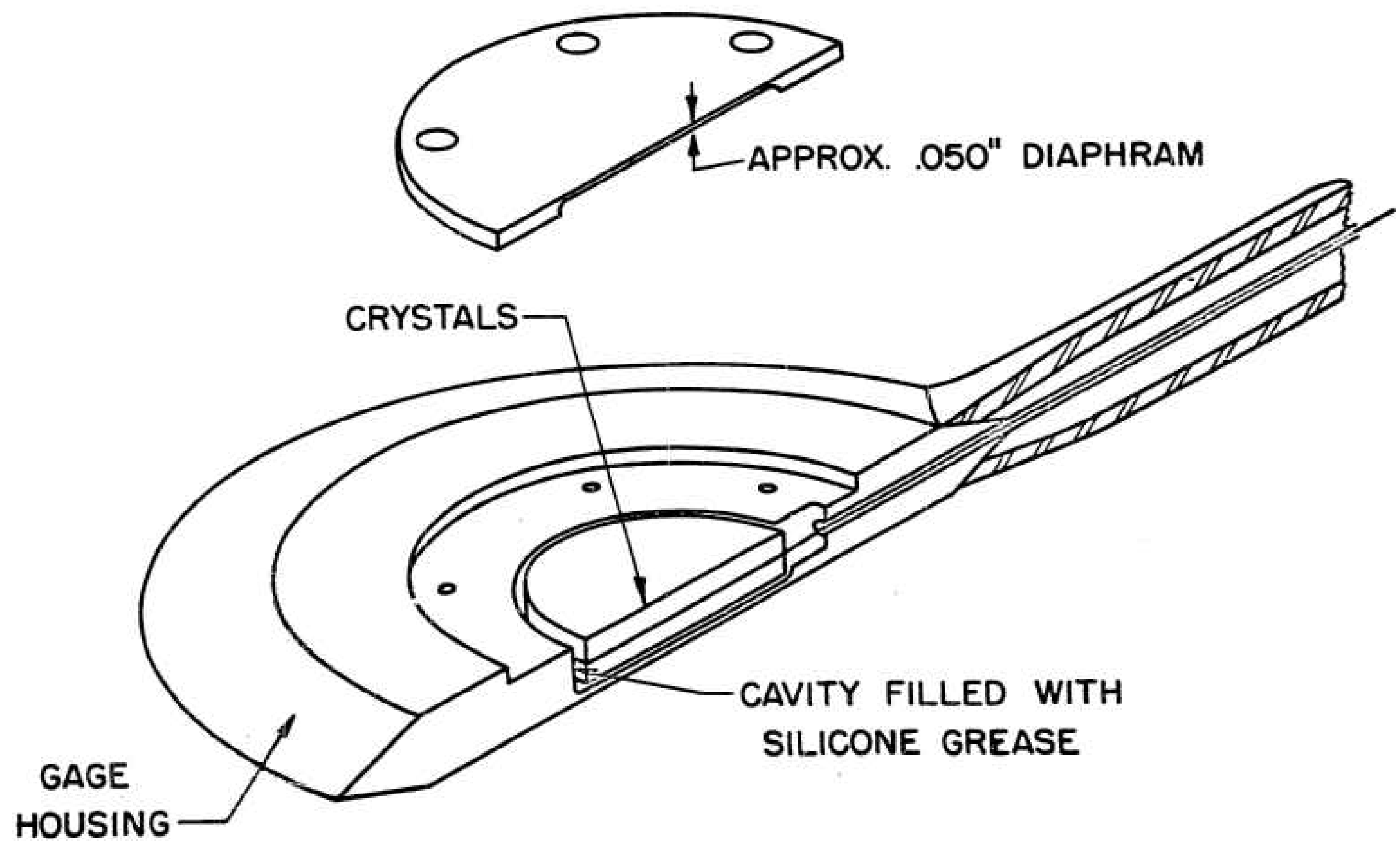
APPROX. .050" DIAPHRAM
CRYSTALS
CAVITY FILLED WITH
SILICONE GREASE
GAGE
HOUSING

Figure 15

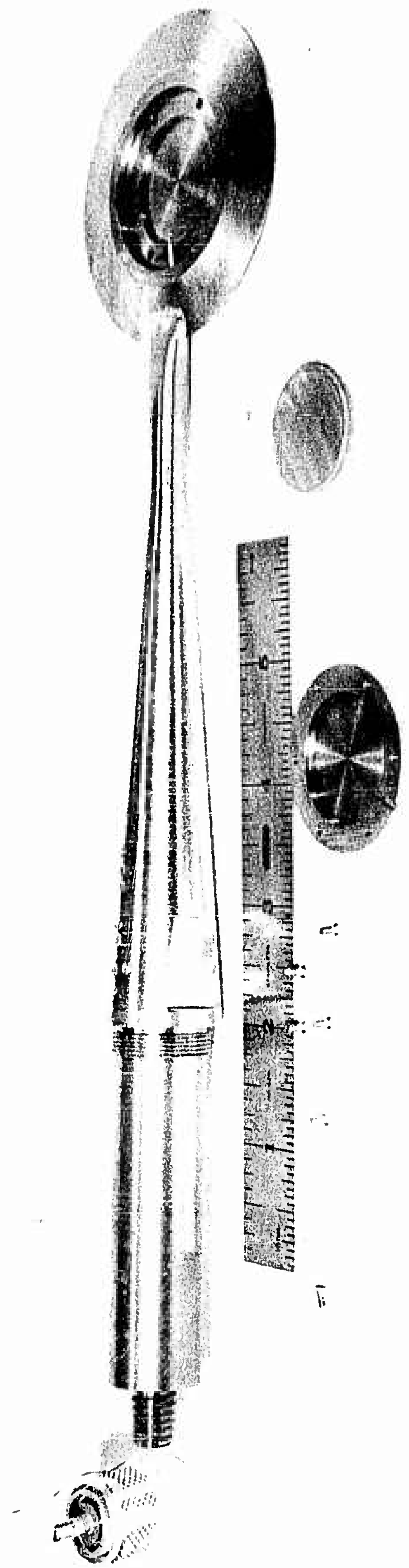

Figure 16

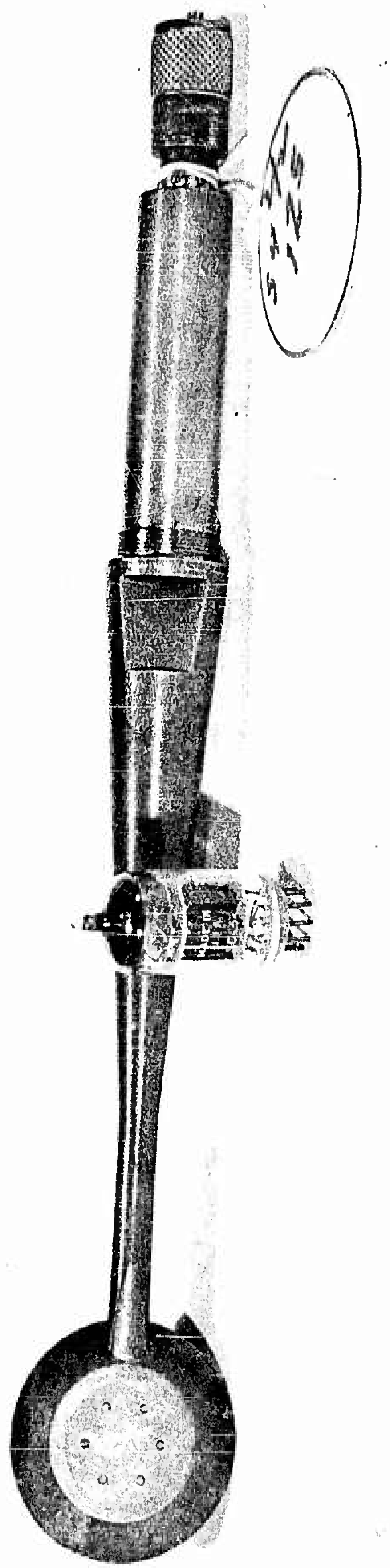

Figure 17

TABLE II

Physical Properties of Lead Metaniobate

Dielectric Constant at 1 KC	225
Dissipation Factor at 1 KC	1.0
Density	5.8 $grams/cm^3$
Poisson's Ratio	0.26
Young's Modulus	3.5 x 10" $dynes/cm^2$
* Curie Temperature	$550^{o}C$ minimum
Resisitivity	7 x 10^{12} ohm-cm
Piezoelectric Constant d_{33}	60 x 10^{-12} coulombs/Newton
Piezoelectric Constant g_{33}	30 x 10^{-3} volmeters/Newton
* Mechanical Q (in radial mode)	11

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A DOUBLE-CHARGE TECHNIQUE TO MEASURE FACE-ON BLAST

W. Olson and J. Wenig

Air blast - Test methods
Pressure - measurement

BRLM Report No. 1347 May 1961

DA Proj No. 503-04-002, OMSC No. 5010.11.815
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